Knemidokoptic mite infections on the Cape Peninsula population of Black Sparrowhawks

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Abstract

Knemidokoptes mites (Acari: Knemidokoptidae) are subcutaneous mites that are found in the skin of the face, legs or body of avian hosts, the symptoms of which can range from featherloss and skin lesions to beak deformities. Although known to infect multiple species of Passeriform birds, very few cases have ever been reported in birds of prey. An unusually high number of Black Sparrowhawks of the Cape Peninsula were identified as being affected by these mites, with obvious symptoms such as baldness and leg lesions. This is the first record of a possible epizootic event caused by Knemidokoptic mites in a wild population of a bird of prey. The number of infection cases elsewhere in South Africa was surveyed and it was found that only rare single cases have been reported, meaning that some causal factor is driving the high infection rate in the Cape Peninsula, where a maximum of 5% of the breeding population were recorded as infected in any one year. The subclinical level of this infection was found to be low, with most of the population not having any mites and only a few individuals representing clinical cases. The infections affect on individual fitness was explored and it was found that it had a significant negative effect on breeding success ($p<0.05$) and productivity ($p<0.01$), but I was unable to preform a survival analysis, due to lack of data. A male bias in infections was detected, but there was no difference in the probability of infection and the morph of the bird in this polymorphic species. These results therefore suggest that this infection has the potential to affect the stability of this population over time, due to its effect on reproductive success. Although this species is not endangered, this possible epizootic event is of interest to the study of bird-parasite systems, specifically how this study ectoparasite can negatively affect the fitness of their hosts.

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Introduction

Parasites as population regulators

A parasite can be defined as an organism that lives in or on a host, from which it acquires food and other biological necessities, as well as reduces the host's fitness (Clayton & Moore, 1997). Hosts with parasites can have higher mortality and morbidity, as well as reduced fecundity. Parasites can either be endoparasitic, that is, live on the inside of their host such as blood parasites, or ectoparasitic, which live and feed on the outside areas of their host, such as mites, lice or ticks. Parasites include bacteria, fungi, viruses, protozoa, arthropods and helminthes (Clayton & Moore, 1997). The interaction between parasites and their hosts has long been an important field of biological study, and bird-parasite interactions specifically are very useful, as they have given many important examples of how parasites can mediate the ecology and evolution of their hosts (Proctor & Owens, 2000).

Parasites can have as important a regulatory role on the growth of host populations as predators or resource limitations may have (Anderson & May, 1979). Populations with some level of parasite are expected to have lower population growth rates or lower equilibrium than populations without parasites, and in this way they may have a limiting effect on populations (Anderson & May, 1979). This is in contrast to the idea that a "successful" parasite would evolve to do little or no harm to its host, and commensalism would be the end result of the interaction between host and parasite (Toft, 1991). After all, it would not benefit the parasite to kill its host, as it would lose its resource. This theory has been disproved, as parasitism's impact on reproduction and survival can be significant and go on to affect the host species' population dynamics and evolution (Toft,

Glossary

Virulence-the relative ability of a organism to cause disease; degree of pathogenicity
Immunocompetence- the potential for immunologic response; capacity to develop immunity to an antigen
Epizootic- a disease or infection that is temporarily prevalent, in which the incidence increases sharply in a population
Vertical transmission- where a parasite or pathogen passes from parent to offspring
Horizontal transmission- where a parasite or pathogen passes between unrelated individuals

1991).

Because parasites actively remove energy resources from their hosts that could be used for other purposes such as growth, maintenance or reproduction, they can have detrimental effects on host life history (Moller, 1997). Parasites are therefore assumed to negatively affect the fitness of their hosts. Hosts have responded by developing numerous adaptions to prevent infection or stop their spread (Sheldon & Verhulst, 1996). Defence mechanisms are hypothesized to be under intense selection as resisting parasite attacks is important when parasitism has been established as a major ecological force that can shape the life-history traits of hosts (Roulin, *et al.* 2007). These compensatory mechanisms can vary from host to host as well as with access to essential resources (de Lope *et al*. 1993).

Parasite costs to avian hosts

Studies have demonstrated increased costs to reproduction events when a high parasite load was present (Moller, 1993 ; Fitze *et al.* 2004) and parasite loads have been shown to have both direct and indirect costs for reproduction (Ricner & Tripet, 1999). Direct cost to current reproduction may occur where increased ectoparasite loads cause longer incubation periods or nestlings with reduced mass (Moller, 1990). Indirect costs of a high parasite load may occur on second breeding attempts (for multi-brooding species) and include a decreased proportion of pairs laying a second clutch, delayed egg-laying and reduced clutch and brood size at fledging (Moller, 1993). By increasing food provisioning to nestlings as compensation for an ectoparasite, parents compromise their future reproduction (Ricner & Tripet, 1999). An increase in parental effort may compensate for the effect of the adult's parasites on their young, however there is a trade-off, because increased parental effort results in a reduction of future reproductive success via lowered immunocompetence and ultimately, survival. Therefore, an increase in parental effort can cause an overall reduction in lifetime reproductive success for parasitized individuals (Fitze *et al.* 2004).

Parasites have also been shown to reduce the survivorship of birds (Hoodless *et al*. 2003; Arriero & Moller, 2008; Brown *et al.* 1995). For example, a study on cliff swallows has shown that when birds were fumigated to remove all ectoparasites,

survival was 12% higher than non-fumigated birds. This reduction in survival translates into nine months less mean life span, and due to the limited breeding season of these birds each year, the reduction in life span can cost one year of lifetime reproductive success for the host (Brown *et al*. 1995). Reduced survival in concert with reduced fecundity can cause population cycles that regulate host numbers (Hudson *et al.* 1998). For example, infection by a parasitic nematode causes population cycles in Red Grouse, by inducing a reduction in host fecundity and survival (Hudson *et al.* 1998). This reduction in fecundity coupled with low parasite aggregation and climatic factors has been found to have a destabilizing effect on this population, causing population cycles (Mougeot, *et al*. 2003).

There may be a trade-off between investment into life history components, such as a large brood or sexual ornamentation, and the host's investment into immune defence (Norris & Evans, 2000). Hamilton & Zuk (1982) proposed that secondary sexual characteristics in males (such as bright colours) are used by females as signals of the male's ability to resist infection by parasites, which can be used in mate choice decisions. The brighter or more complex the signal, the more resistant to parasites the males are predicted to be, which could increase the viability of offspring (Hamilton & Zuk, 1982). This hypothesis was then extended to include the fact that increased testoterone , while enhancing secondary sexual characteristics, can limit the immunocompetence (Folstad & Karter, 1992). Immunocompetence of the host plays a role in the ability of hosts to withstand parasites, and therefore increased investment in costly traits may increase risks of parasitism (Norris & Evans, 2000).

The sex of a host can cause variation in parasite levels, with males being more parasitized than females due to fundamental biological and behavioural differences (Christe, *et al.* 2007). Such a male bias has been established for both birds and mammals (Poulin, 1996). As discussed above, steroid hormones such as testosterone can supress the immune system of males (Folstad & Karter, 1992). Also, behavioural differences such as aggression between males or decreased male grooming during the mating season may also account for the bias and lead to increased likelihood of infection (Christe, *et al.* 2007). Mating systems such as

polygyny, due to increases in physiological stress, may also impose sex-biased parasitism in birds (McCurdy, *et al.* 1998). Age can be comparably significant in determining parasite levels. For example, Deviche et al. (2001) found that older male Dark-eyed Juncos had significantly higher parasite prevalence than younger males, possibly due to differences in gonadal hormones or differences in hormonal exposure. A similar trend has been found in Great Tits (Norris et al. 1994) and Red-winged Blackbirds (Weatherhead & Bennett, 1991). Therefore both age class and sex can cause a bias in the parasite loads of their avian hosts.

Habitat types may also play a role in parasitism. For example, the change from wild to urbanized environments may affect parasite-host interactions (Delgado & French, 2012). Changes to parasite loads in urban areas can influence the prevalence and impact of wildlife diseases in urban areas, and changes in parasite-host interactions in urban areas (compared to rural areas) may influence which species are able to be successful in cities (Delgado & French, 2012). Species that are rare in urban environments may be more susceptible to parasites compared to commoner species, and therefore susceptibility to parasites influences which species can flourish in an urban environment (Delgado & French, 2012). Parasite abundance may be either higher or lower than rural areas, with this pattern being location, host and parasite specific. Increased presence of exotic species, poorer habitat quality and depression of immune systems by pollutants may result in increased parasitism in cities, but conversely pesticides may inhibit ticks and other ectoparasites, and increased food availability may lead to a stronger immune system and therefore fewer parasites (Delgado & French, 2012). Urban environments may also affect traits such as colour morphs and their associated parasite prevalence. For example, dark morph feral pigeons have similar parasite prevalence across all urbanization gradients, while light morphs are less parasitized in moderate urbanization, but their parasite prevalence increased with more intense urbanization (Jacquin*, et al*. 2013). Therefore it can be concluded that urbanization and its associated changes to habitat can be an important factor in host-parasite dynamics.

Knemidokoptic mites

Mites are a very taxonomically diverse group of arachnids, and have developed parasitism on multiple different phylogenetic occasions (Proctor & Owens, 2000). The relationships found between mites and their avian hosts are very diverse, and can range from detrimental to beneficial for their hosts (Proctor & Owens, 2000). There are at least 2500 species of mites that are dependent on birds (Proctor & Owens, 2000). The skin, respiratory passages and feathers can provide mites with a suitable microhabitat, and mites can become incredibly specialized to a certain region of these three areas. Feathers have the greatest diversity of mites associated to them (Proctor & Owens, 2000). Mites that feed on living tissues can be detrimental to the host in many different ways- from causing anaemia to causing asphyxiation (Proctor & Owens, 2000). Feather mites may be less harmful as they are more likely to be commensal or mutualistic with their hosts while blood feeding mites are often harmful to hosts reproductive success due to their effects on chicks (Proctor & Owens, 2000). Most mite species are transmitted via direct contact with mates, offspring or colony members, while hippoboscid flies may transfer other species (Proctor & Owens, 2000). It is predicted that mites transmitted horizontally (that is, between unrelated individuals) may be more virulent than those transmitted vertically (that is, from parent to offspring or vice versa). To avoid mite infection many species use behaviour, such as avoiding re-using old nests, lining nests with aromatic foliage or grooming, or more rarely, immunological defences (Proctor & Owens, 2000).

Knemidokoptes mites (Acari: Knemidokoptidae) are subcutaneous mites found in the skin of the face, legs or body of avian hosts and feed off host tissues, or eat the pith of the quill (Proctor & Owens, 2000; Dabert *et al.* 2013). Four species of these mites commonly infest both wild and captive birds, namely *Knemidokoptes mutans, K. fossor, K. jamaicensis* and *K. pilae* and can result in the condition known as "scaly leg" or "scaly face" (Kirmse, 1966). Feather loss, lesions on the face or around the beak or lesions and encrustations on the legs characterize this condition (Pence *et*

al. 1999), and the proliferation of growths can cause beak deformities, or possible loss of digits (Pence, 2008; Goulding, *et al.* 2013). When the mites are responsible for depluming, the mites burrow into the basal shafts of the feathers. Mechanical trauma for the burrowing action of these mites, as well as excretory products cause the observable changes to the skin (Pence, 2008). The conditions "scaly face" or "scaly leg" appears to advance slowly in most hosts, with slow development of lesions. The mites complete their entire life cycle on a single host (Kirmse, 1966). The two most studied species of these mites are *K. jamaicensis,* which is responsible for individual cases as well as epizootic events on passerines, and *K. pila*e, which is mainly responsible for head and body mange in captive birds (Pence, 2008).

An epizootic event is a disease or infection that is temporarily prevalent, in which the incidence increases sharply (Oxford Dictionary, 2013). A random isolated case of clinical infection may be expected in a population, but greater numbers of clinical cases are apparent for these mites than is 'expected', which indicates an epizootic event (Pence *et al.* 1999). Subclinical infections of these mites are not well known however (Pence *et al.* 1999). This propensity to cause epizootic events has been documented in poultry, caged domestic birds, and increasingly in wild birds (Pence *et al.* 1999). Knemidokoptic mite epizootics have been reported in American Robin (*Turdus migratorius*), Red-winged Blackbird (*Agelaius phoeniceus*), Common Grackle (*Quiscalus quiscula*), brown-headed Cowbirds (*Molothrus ater*), Evening Grosbeak (*Coccothraustes vespertinus*), Chaffinch (*Fringilla coelebs*), Sedge Warbler (*Acrocephalus schoenobaenus*), European Bee-eater (*Merops apaister*), and Eurasian Tree Sparrow (*Passer montanus*) (Pence, 2008). *Knemidokoptes* infestations appear to be uncommon in birds of prey however (Miller *et al.* 2004). From the published literature, I was only able to identify known infections of raptors by Knemidokoptic mites in an individual captive Swainson's hawk (Miller *et al*. 2004), a captive Great-Horned owl (Schulz *et al.* 1989) and a captive hybrid falcon (Heidenreich, 1997). Latta & O'Connor (2001) describe that the current number of known wild hosts is restricted to about 20 species of Passeriform birds, from a variety of families.

Only two studies have explored the fitness consequences that *Knemidokoptes* mite infections may have on wild birds. They describe the detrimental effects of *Knemidokoptes jamaicensis* on winter resident Prairie and Palm Warblers in the Dominican Republic. Latta & O'Connor (2001) found that birds with mites were more common in dry desert scrub than at higher elevations and moist habitats, and that there was a relationship between dry habitat type and the prevalence of infections. Latta (2003) found that infection intensity appeared to vary seasonally with increased prevalence seen in late winter. Sex and age did not seem to be important variables for infestation. The mites caused significantly reduced muscle mass scores, lowered site persistence, and had a very significant effect on annual return rates after migration, which can be used as a proxy for the effect of mites on survival (Latta, 2003)

Latta argued that both environmental and behavioural factors could affect rates of mite infestation. Environmentally, a dry environment like that of the desert thorn scrub could exert greater physiological stress than moist habitats, which could promote transmission to a weakened bird. Suboptimal habitats may necessitate the birds increasing the time and energy they spend foraging, and this cost may suppress immune function (Latta, 2003). Another alternative may be that a dry desert habitat may be conducive to a favourable mite microclimate, aiding its survival and reproduction. Behaviourally, communal roosting (such as found in desert habitat, but not in moist habitats) may increase transmission, leading to greater prevalence among this population (Latta, 2003). A compromised physiological condition increases the chance of mortality through other factors such as predation, even though mite infection may not be fatal in itself. (Latta, 2003)

The only study conducted on Knemidokoptic mites in Africa focused on the Cape Wagtail population of Dassen Island. Goulding*, et al.* (2012) found that infection by *Knemidokoptes jamaicensis* was more than double as prevalent on this island compared to the mainland and that larger individuals were more likely to exhibit signs of infection. It was suggested that the low levels of predation which are likely to be found on this island may allow badly affected individuals to survive for

longer periods than they might where aerial predators are more common. It was also proposed that the high proximity between individuals and communal roosting behavior may contribute to the spread among this population (Goulding *et al.* 2012).

The Black Sparrowhawks of the Cape Peninsula

Black sparrowhawks are a relatively recent immigrant to the Cape Peninsula, with the first successful breeding attempt recorded in 1993 (Oettle, 1994). Since then the population has increased substantially to an estimated 50 breeding pairs (Martin *et al*. 2013). The Black sparrowhawk's range traditionally includes Zimbabwe, Swaziland, eastern and extreme southern South Africa, as well as well-wooded regions of West, East and Central Africa. Its favoured habitat is forest, riparian growth and woodland (Allan, 1997). It is adapted to nesting in alien tree stands, which could be responsible for the extension of its range into areas that naturally have little forested habitat, such as the Cape Peninsula (Malan & Robinson, 2001). Most operational commercial forests do not reach the required height for nesting, so sparrowhawks exploit experimental or abandoned planted forests of aliens (Malan & Robinson, 2001). It has an avian diet, consisting mainly of pigeons, doves, francolins and domestic fowl (Allan, 1997). Because of this diet, Black Sparrowhawks are able to forage extensively in urban spaces, as their favoured prey is abundant all year round in these areas. Indeed the Black Sparrowhawks on the Cape Peninsula have benefited from urban sprawl and habitat modification as it provides them with increased prey and alien trees for nests. This ability to thrive in modified environments may be responsible for their ability to have multiple broods in a year, and the extension of their breeding season to up to nine months (Curtis, *et al*. 2005). The subsequent steady population increase since their colonization is most likely as a result of their ability to take advantage of the urban setting.

Despite the Black Sparrowhawk's general success on the Cape Peninsula, a new threat to this population may be emerging. A number of birds with balding heads and/or leg lesions have been seen, although the possible impacts on survival or

breeding success have not been assessed. A post mortem on a bird in this condition confirmed that Knemidokoptic mites were associated with these symptoms. This is unusual, as very few birds of prey seem to be affected by these mites, and certainly not at the numbers suspected to be present in the Cape Peninsula population of Black Sparrowhawks. The dead bird that the post-mortem was performed on was in very poor body condition, with no fat reserves and showed severe pectoral muscle atrophy. There was featherloss on the crown and forehead with crusting and abrasions, and the exposed leg areas had areas of ulceration and abrasion. Skin scrapings revealed the presence of mites suspected to be of the Knemidokoptes species. A severe mite infestation was determined as the cause of death (MacGregor, 2012).

Although Black Sparrowhawks are not threatened, it is of interest to find if an urban environment, the Mediterranean climate of the Cape or some other factor, is contributing to the unusually high infection rates apparently present in this population. Therefore in this study I will investigate this phenomenon in more detail to describe the frequency of occurrence and to examine the influence that infection might have at an individual level. I hypothesise that subclinical infection rates in Cape Peninsula Black Sparrowhawks may be high, and this will be tested by examining post-mortem specimens for mites. I hypothesise than birds infected by Knemidokoptic mites may have negative fitness consequences, which will be tested by comparing survival and breeding success and productivity performance between infected and uninfected birds. I also hypothesise that weather may play a role in the number of infections, such that in dry or cold years, more infections are expected, based on the findings of Latta (2003). Finally, we hypothesise that *Knemidokoptes* mites may be causing an epizootic event on the Cape Peninsula, which will be investigated using other studies from around South Africa for a comparison of infection incidences.

Methods

Prevalence of infection within the Cape Peninsula study individuals used for statistical analysis

The occurrence of individual Black sparrowhawks on the Cape Peninsula showing symptoms of Knemidokoptic infection was recorded over a period of nine years (2004 to 2012), which also specified the sex, morph, location, year and body area of infestation. Regular monitoring of the entire population during this time recorded data about productivity, disappearances, divorces (for ringed birds) and other events, using the database collected by Martin (2012, unpublished data) on each breeding individual in all known territories on the Cape Peninsula. Even if an individual was not ringed their breeding records could be discovered because of the possibility that their partner for that year was ringed, as well as the fact that this species is polymorphic, making individuals of different morphs easy to distinguish. Therefore, if an infected bird was breeding in a particular territory for a specific year, and their partner was ringed, their breeding history for that year would be known.

Subclinical and clinical mite presence on Black Sparrowhawks

The prevalence of subclinical Knemidokoptic mite infections was investigated on 19 deceased Black Sparrowhawks, which had been found dead from various causes and were then donated to this project. Skin scrapings were taken from a random leg and from the head of the birds using anatomical markers, namely, the halfway point of the tarsometatarsus, at both front and back of the leg, from the top or side of each toe and from the crown of the bird's head. A total of seven skin samples were taken from each bird. The scrapings were taken from just under the leg scales or feathers of the bird, using a scalpel, and placed on individual slides. A small amount of potassium hydroxide (10% KOH) was added to each scraping, in order to macerate the waxy layer of the scales and skin (Schulz, *et al.* 1989; Pence, *et al*. 1999). A coverslip was then used, and the slides examined at 40x magnification with a compound microscope (no oil immersion). The presence and abundance (as

the total count per slide) of mites was noted for each slide. All slides received the same search effort of about 5 minutes search per slide. The post-mortem individual's samples were used as a positive control, such that mites on the other carcasses were only recorded as such if they were similar in appearance to the mites found on the post-mortem individual.

Weather and mite infections

The percentage of newly infected black Sparrowhawks was calculated from the proportion of new infections out of the total breeding population for that year and then multiplying this by 100. To normalize this data an arc-sine square root transformation was used. This was then compared to the average rainfall in summer and winter, and then to year-round average rainfall for each of these years. Average rainfall was found by averaging monthly total precipitation values from 'The Tropical Rainfall Measuring Mission' (TRMM) found in Climate Information Portal (CIP: http://cip.csag.uct.ac.za/webclient) for the years 2004 to 2012. The weather station used was the Cape Town airport station. Winter was taken to be from May to October, and summer from November to April, starting in the previous year. This was because only the preceding summer could influence the number of infection events present in any year. The percentage of new infections per year in the breeding population was then compared to the average temperature for 'winter 'and 'summer' months, which were found from the historical weather section of Weather Underground, Inc., (2013) for all years between 2004 and 2012.

Establishing infection rates elsewhere in South Africa

The occurrence of Knemidokoptic mite infections elsewhere in South Africa was also explored, and compared to the Cape Peninsula. The other authors/members of public contacted for information about possible infections in other regions are summarized in Table 1. For each of these populations of Black Sparrowhawks I obtained information on the number of 'pair years' monitored and the number of infected birds seen. An article was also placed in African Birdlife magazine

(May/June 2013) requesting sightings of Black Sparrowhawks with possible symptoms of mite infections, which yielded one positive response (Appendix, Fig. 2). The GPS co-ordinates of general locations of study were plotted onto a map of South Africa, using R, and marked as infected or uninfected. Nest sites that had been studied were grouped into general locations, to make one point per area, for example, all nest sites noted as from around Richards Bay were plotted as a single point and were labeled as either infected or uninfected. Secondly, the sample size (number of 'pair' years studied) was found for each of these general locations around South Africa, and compared to the number of infected birds reported. These were then plotted as pie charts of infected and uninfected for that location, and plotted on a map of South Africa. The sizes of the pie charts relative to each other give an indication of sample size i.e. the larger the size of the pie chart, the larger the sample size.

Table 1: Sources of data from other Black Sparrowhawks nests monitored across South Africa used in this study

Author	Reference	Years	Locations	Number of 'pair' years
W. Tarboton	Tarboton & Allan, 1984	1976-1980	Nylsvley	118
E. Wreford	Unpublished	2012	Kwa-Zulu Natal	22
G. Malan	Malan & Robinson, 2001	2001	Across S.A	58
H. Chittenden	Unpublished	2010-11	Kwa-Zulu Natal	2
"Firefly"	http://fireflyafrica.blogspot.com/2012/07/black-sparrowhawk.html	2012	Port Elizabeth	1
Martin	Unpublished	2001-2012	Cape peninsula	430
TOTAL				**631**

Statistics

Weather analysis statistics

The relationship between normalized percentage of new infections in the Cape Peninsula breeding population and average winter temperature and rainfall, average summer temperature and rainfall, and year-round average rainfall for each year between 2004 and 2012 was studied. A correlation analysis was run in STATISTICA for each of these interactions to determine whether a trend could be found, and whether the correlation was significant.

In order to discover whether climate may explain infection cases elsewhere in South Africa, correlation analyses in STATISTICA were run on the number of infected 'pair years' at each study site and the average winter rainfall, the average summer rainfall and the average year-round rainfall (mm), the average maximum summer temperature, the average minimum winter temperature and the average year-round temperature. Data was collected from the historical seasonality at each GPS location, using 'The Tropical Rainfall Measuring Mission' (TRMM) from the Climate Information Portal (CIP: http://cip.csag.uct.ac.za/webclient), and was found by averaging the monthly values for each variable.

Statistical analysis of variations in infection occurrence between morphs and between sexes

In order to find whether one of the morphs (dark or light) or either sex was infected at a significantly higher rate than expected a chi-squared test was preformed, using STATISTICA, on the data from all infected individuals. The fact that 76% of the Cape Peninsula population of Black Sparrowhawks are dark morphs (Amar, *et al.* 2013) was used to find the proportion of dark and light morphs that would be expected to be infected from all observed infected individuals (n=20). A sex ratio of 1:1 was used to estimate the expected number of male and female infected individuals from all observed infected individuals of known sex (n=14) (Appendix, table 3 & 4).

Statistical analysis of effect of infection on breeding success, productivity and survival

To discover the effect of infection on breeding success and productivity a generalized linear model (GLM) was carried out using R Studio, version 0.97.449 (R Core Team, 2013). The relationship between infection and breeding success, and between infection and productivity were analysed. Breeding success was treated as binomial (1=successful breeding event, 0= unsuccessful breeding event) where breeding success was listed as 0 if the nest failed at any stage between courtship and the chicks leaving the nest. Productivity was the number of chicks surviving to leave the nest in that breeding event, and ranged from 0 to three chicks, and approximated a Poisson distribution (Appendix, Figure 1). The effect of one individual's long-term infection and therefore the lack of independence between multiple data points was accounted for by re-running the analysis using a generalized linear mixed model (GLMM), with bird ID specified as a random term. A database was created recording the breeding success and productivity for each breeding event of each infected bird, which was then used for the GLM and the GLMM analyses (Table 2). There were data on breeding success and productivity for nine of the infected birds, and six of the infected birds had survival records. The number of years of data varied depending on when the bird was ringed. There was reason for more data for breeding success and productivity because even when an infected bird was un-ringed, the pair could be identified via their morphs, and when the bird's inferred partner was ringed, their breeding success and productivity was known for that breeding event. However, survival could only be inferred from ringed birds, because if unringed birds changed territories/partners they would not be identifiable. If this were to happen this bird may be wrongly listed as "suspected dead" because of their absence from their old territories. Survival was not analysed with GLM/GLMM, due to lack of data for the required analysis.

Table 2: Productivity database used for GLM and GLMM for each infected Cape Peninsula Black Sparrowhawk with an identifiable breeding history, indicating the number of chicks successfully hatched in a year. Yellow shading indicates start of infection, and green shading indicates year suspected dead.

	Year											
Individual (ring no./ territory)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Newlands 2							0	0				
LTF1F1	0	3	0	3	3	3	0	0	0	0		
687858							0	0	0	0	2	
Northern border								1	0			
Ottery											2	0
Dassenberg											2	0
6HO3248									0	2	1	0
687869									0	0	0	0
687876										2	2	0
784931											0	0

Results

Within the Cape peninsula, there were 20 infected birds recorded over the period between 2005 and 2013, of these 11 were part of a breeding pair, and therefore had known breeding records. Data are summarized in Table 3. Characteristics of each infected bird listed in Appendix Table 1 & 2.

Mite prevalence on Black Sparrowhawks

Out of 19 Black Sparrowhawk carcasses that had been donated to this project and were sampled for sub-clinical infections, 3 were infected with mites. The post mortem specimen and one other bird were severely infected, with as many as 20 mites found per skin sample. The symptoms of these birds were very apparent, both being completely bald. The symptoms on the post mortems specimen's legs were very obvious, while the other heavily infected bird's legs were 'scaly' but with no lesions. Only two mites were found on the third infected bird, indicating a low level of infection. This bird showed no obvious external symptoms, with no featherloss on the head but some small lesions on the legs. Nine of the nineteen birds sampled were male, four were female, and six were classified as juvenile, where sex is unknown (Figure 1). All mite cases were found on male birds. No females or juveniles showed any sign of mite infection.

Table 3: Summary of infected Black Sparrowhawk study individuals from the Cape Peninsula

		# Of Individuals
Sex	Male	11
	Female	3
	Unknown	6
Morph	Dark	13
	Light	7
Total	Part of a breeding pair	11
	Unpaired	9

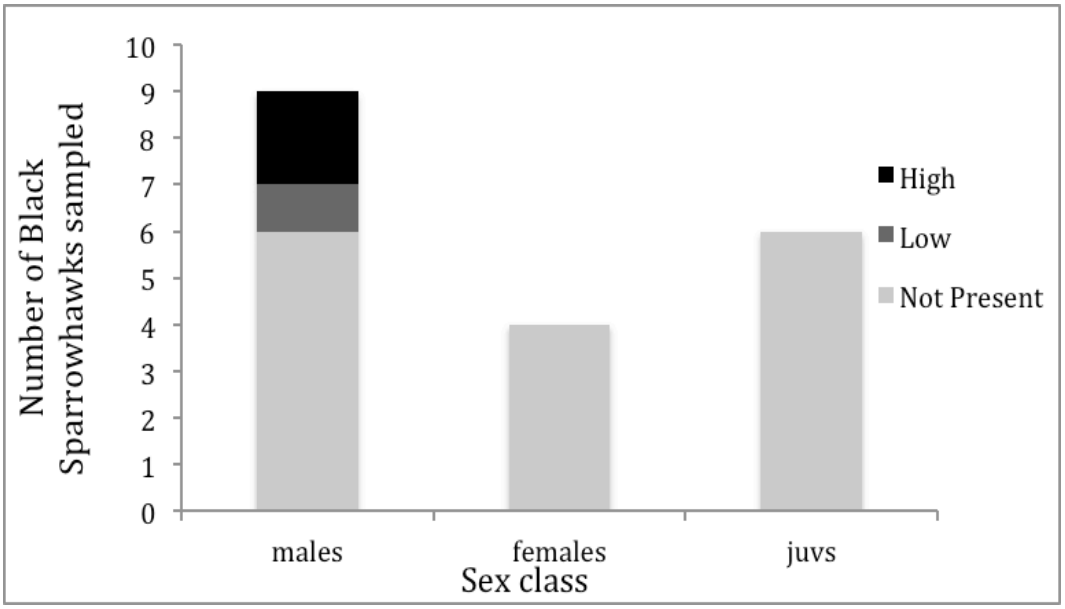

Figure 1: Numbers of each sex class of Black Sparrowhawk sampled, with a breakdown of each class for mite presence. High mite numbers are represented by black, low numbers by dark grey and no mites ('not present') by light grey

Weather and new infections

Although there was a suggestion of a trend between new infections and average winter rainfall (Figure2), the correlation analysis suggested that these factors are not strongly correlated: no significant correlation between the percentage of birds newly infected in the breeding population and the average winter rainfall exists ($p>0,05$, $n=9$). The trend between winter and summer temperatures and new infections (Figure 3) provides some support for a negative relationship between the average winter temperature and the percentage of new infections in the breeding population, although this was not quite statistically significant ($p=0,15$, $n=9$) (Figure 4). There was no correlation between the average temperature over the summer period and the percentage of new infections, or between average summer rainfall and percentage new infections ($p>0,05$, $n=9$), (Table 4).

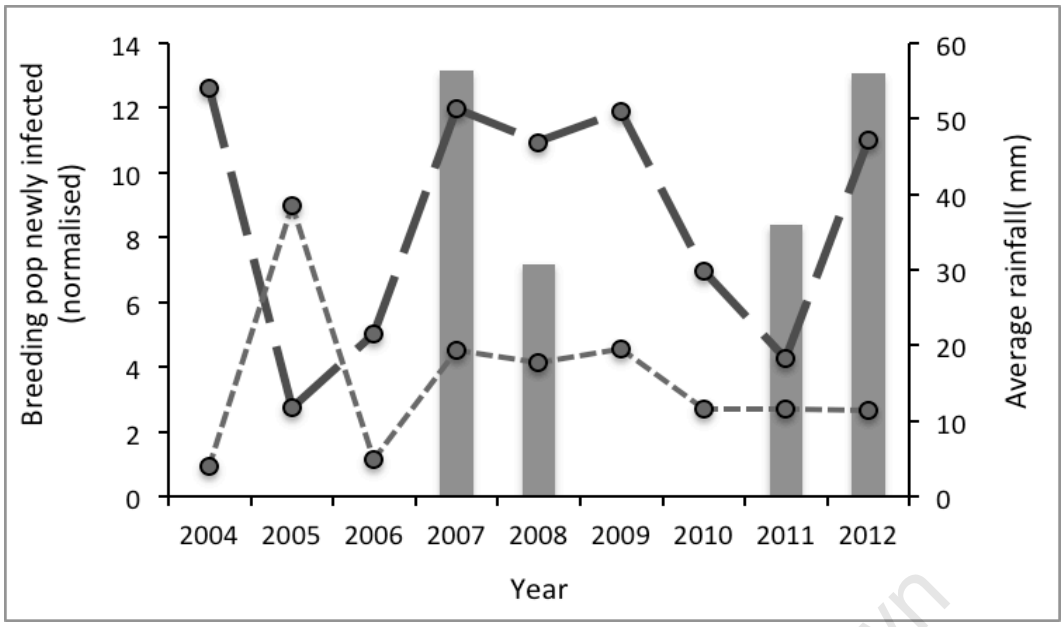

Figure 2: Normalized percentage of breeding population of Black Sparrowhawks newly infected with mites per year, (bars) with average winter (large dashed) and average summer rainfall (mm) (small dashed) for each year.

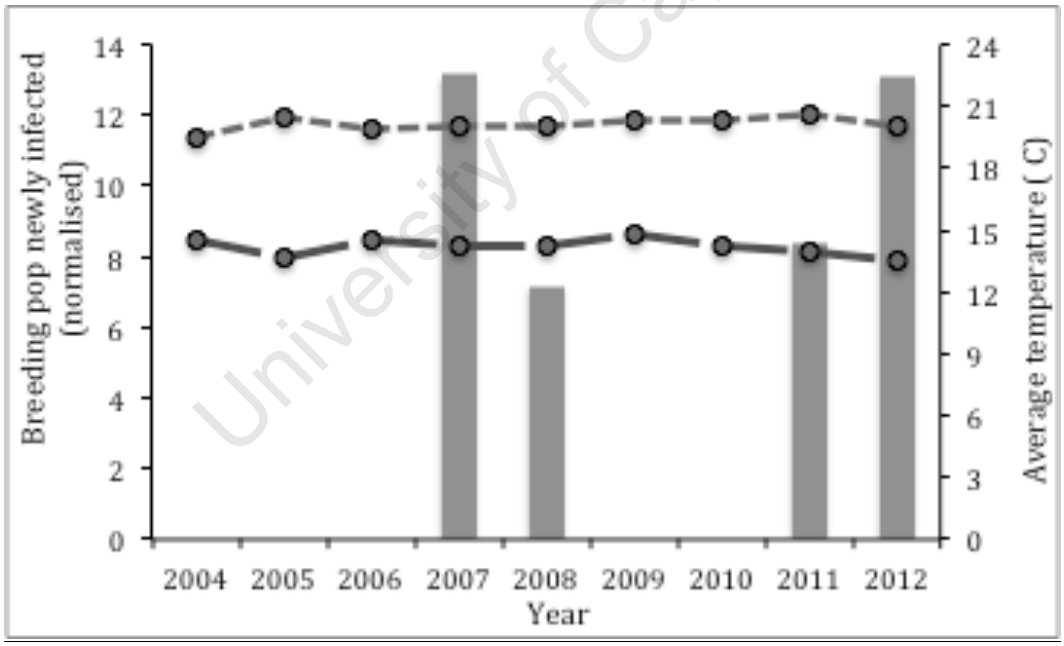

Figure 3: Normalized percentage of breeding population of Black Sparrowhawks newly infected each year (bars), with the average temperature (°C) for winter (large dashed) and summer (small dashed) for each year

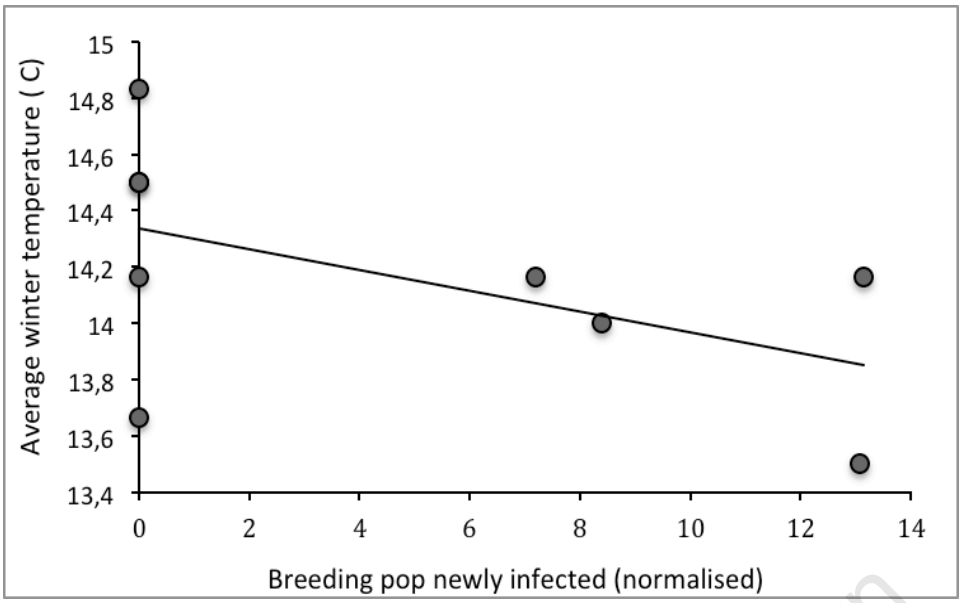

Figure 4: Scatterplot of normalised percent breeding population newly infected and the average winter temperature (°C) for 2004-2012 (R^2 = 0,27, p=0,15, n=9)

Table 4: Correlation results of climate variables to normalized percent breeding population newly infected, showing significance level

Climate variable	Mean	St dev.	R^2	p-value
Average winter temperature (°C)	14,16	0,42	0,27	0,15
Average winter rainfall (mm)	36,85	16,47	0,09	0,41
Average summer temperature (°C)	20,12	0,36	0,01	0,98
Average summer rainfall (mm)	15,44	10,34	0,01	0,93

Mite infections on Black Sparrowhawks in other regions of South Africa

Only three areas of South Africa besides the Cape peninsula had reports of Black Sparrowhawks with symptoms of mite infection such as balding and leg lesions. These were in Port Elizabeth, inner Kwa-Zulu Natal, and around the Durban area (Figure 5). No infections were reported in the entire interior of the country. This included the regions of Gauteng, the Free State and parts of Limpopo.

The infections outside of the Cape Peninsula appear to be isolated individuals, with the majority of the population exhibiting no obvious signs of mite infection. This area was the most intensively sampled (Figure 6). Durban and surrounds was next most intensively sampled by Malan and then subsequently by Wreford, and

reported 3 infections out of 29 'pair' years. There was fairly extensive sampling in the Transvaal area (Nylsvley), preformed by Tarboton & Allan (1984), with 118 'pair' years monitored with no infection reported. Malan & Robinson (2001) performed the majority of the monitoring outside of this area and the Cape Peninsula. However, the majority of the nests monitored by Malan and Robinson (2001) were monitored for only a short period, and therefore don't represent the same study effort that the Cape Peninsula and the Nysvley areas do.

There were no significant correlations between any of the climatic variables and the number of infected pair years at all study sites (Table 5). Average winter rainfall was the most significant of all climate variables, although still not significant (p=0,27, n=18).

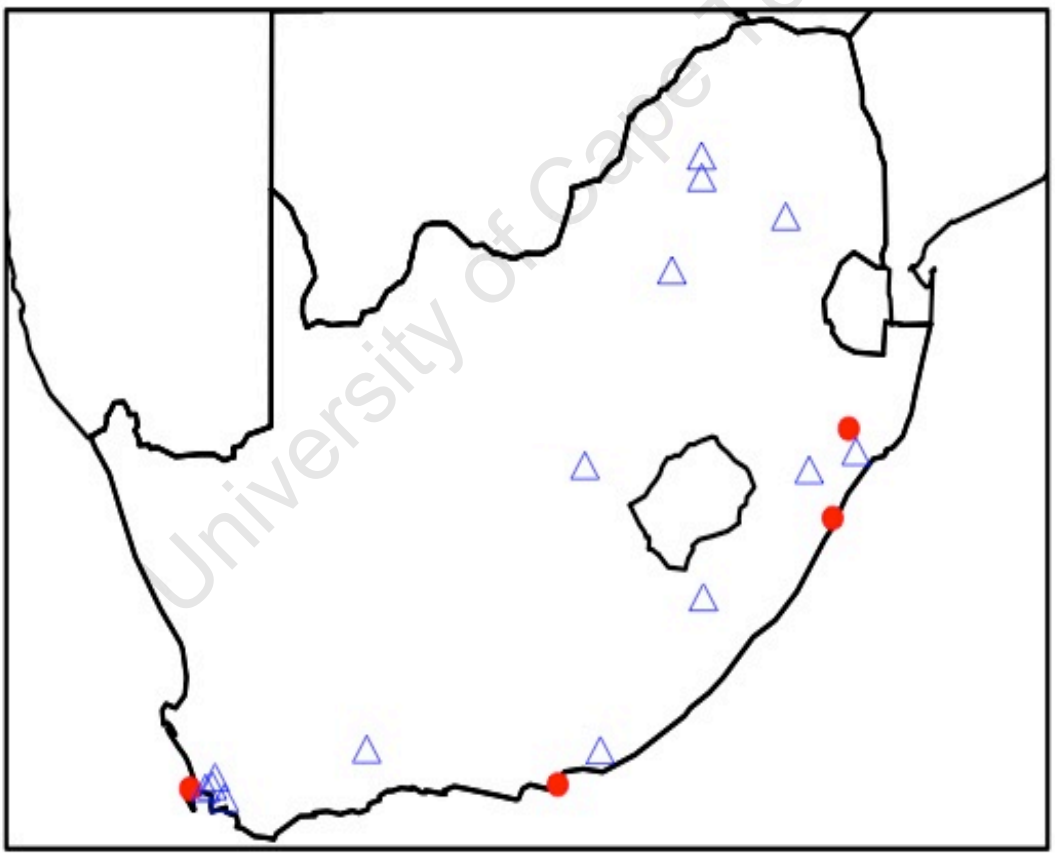

Figure 5: Map of Southern Africa showing Black Sparrowhawk study sites, where a blue triangle indicates no infection reported, and a red circle indicates known incidences of infection

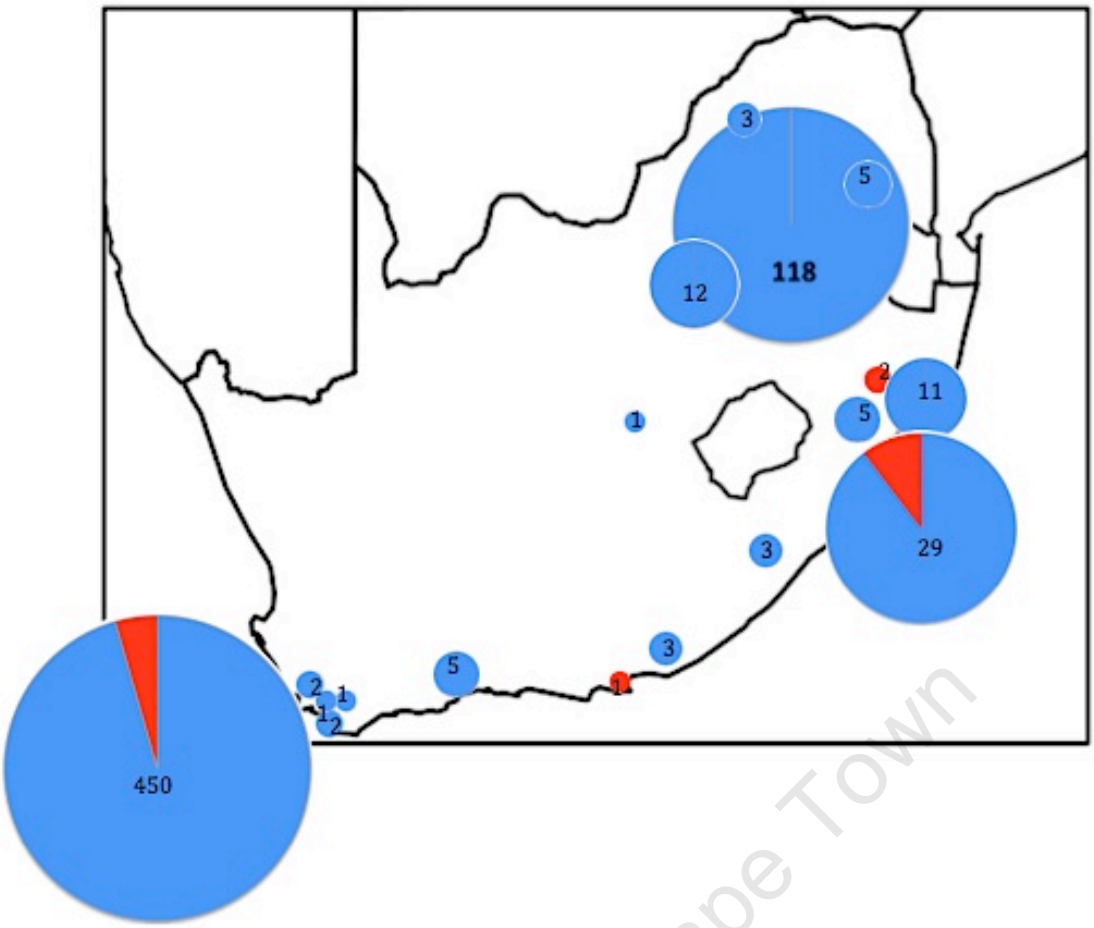

Figure 6: Map of Southern Africa showing number of 'pair' years that Black Sparrowhawk were monitored for in various regions, where the blue portion of each pie chart represents the proportion of the total 'pair' years studied that were uninfected, while red indicates the proportion of nest years studied that were infected

Table 5: Correlation results of climate variables to number of infected 'pair years' at all locations of study around South Africa, with significance level

Climate variable	Mean	St dev.	R^2	p-value
Average min winter temperature (°C)	8,40	2,94	0,01	0,71
Average max summer temperature (°C)	25,99	1,75	0,02	0,59
Average year-round temperature (°C)	17,19	1,60	0,00	0,96
Average summer rainfall (mm)	65,29	37,56	0,05	0,36
Average winter rainfall (mm)	42,92	24,08	0,07	0,27
Average year-round rainfall(mm)	54,1	19,07	0,00	0,83

Mite identification

The samples from the three Black sparrowhawks that had a mite infection were examined microscopically and confirmed to be Knemidokoptes spp. Mites were seen in burrows they had excavated into the skin at a subcutaneous level (Figure 7). The mites were often seen separate from the main sample on the slide, indicating that the technique implemented efficiently captured mites, in their burrows or otherwise (Figure 8). The physical symptoms of these mites on their Black Sparrowhawk hosts can be seen in Figure 9. The mite were identified as *Knemidokoptes* spp. by Miss Heloise Heyne of Onderstepoort Veterinary Institute, and were suggested to be either *Knemidokoptes laevis* (a depluming mite of domestic fowls), *Knemidokoptes mutans* (causes scaly leg in domestic fowls) or *Knemidokoptes pilae* (causes scaly leg in caged birds), although *Knemidokoptes jamaicensis* may be another possibility as the Cape Wagtails of Dassen island were infected by this species.

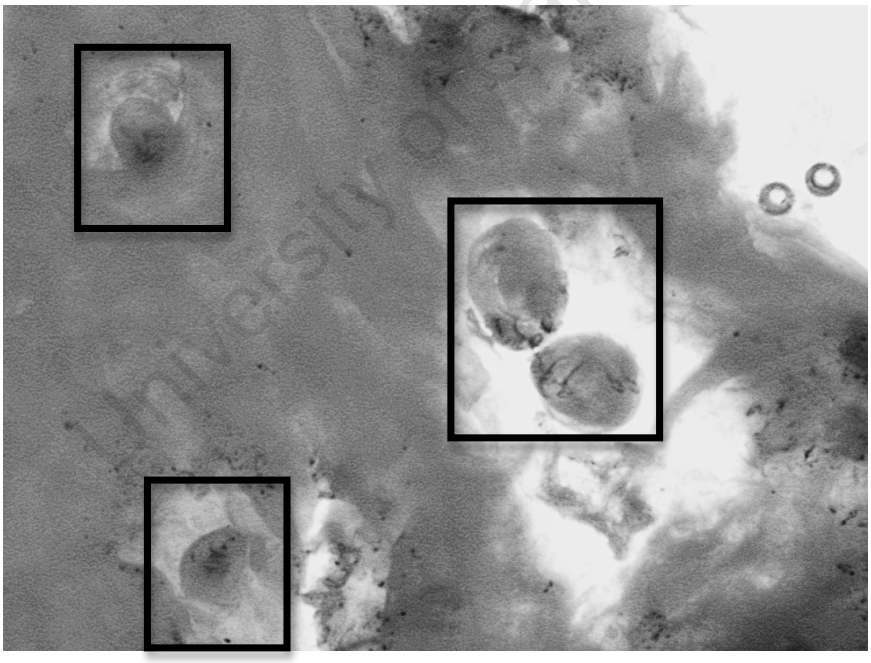

Figure 7: Photograph of mites found in skin scrapings taken from the Post-mortem Black Sparrowhawk, showing Knemidokoptic mites in their skin burrows

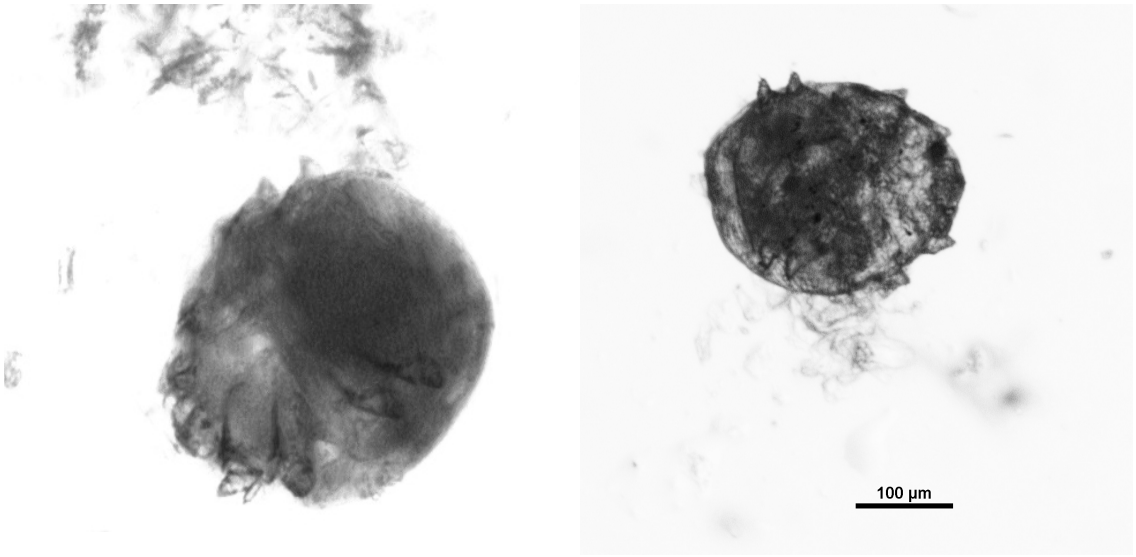

Figure 8: Photograph of mites found in skin scrapings taken from the Post-mortem Black Sparrowhawk, showing individual Knemidokoptic mites

Figure 9: Female Black Sparrowhawk with symptoms of mite infection (bald heads, and severe leg lesions) investigating another Black Sparrowhawk pairs nest. Photograph courtesy of Gareth Tate

Differences in occurrence of infection between morphs and between sexes

Out of the 20 infected birds 13 were classified as dark morphs and 7 as light morphs. This ratio did not differ from expected given the proportion of dark and light birds in this population, where dark morphs are more prevalent (76% dark morph). There was no significant difference between infected dark and light morphs in the number of cases of infection ($\chi^2 = 1{,}327, p = 0{,}2494, n = 20$). Out of 14 infected birds of known sex, there were 11 males and 3 females. The proportion of males infected was significantly higher than would be expected, assuming a 1:1 sex ratio ($\chi^2 = 4.571, p = 0.033, n = 14$).

Effect of infection on breeding success, productivity and survival

Breeding success and productivity were both significantly negatively affected by infection (Table 5). Productivity of infected birds was lower after they were infected that before they were infected (Table 6). Due to lack of data survival could not be statistically analysed, however from the six ringed individuals with some data it was observed that 50% of them were not re-sighted the following year. This can be compared to survival for the whole Cape Peninsula population of Black Sparrowhawks, where survival to the following year ranges from 84 to 88%, while re-sighting in the following year ranges from 84 to 96%.

Table 5: Results of GLMM analyses, testing the effect of infection on breeding success and productivity (n=10) of Black Sparrowhawks of the Cape Peninsula

Factor	Variable	Chisq	D.f	Pr(>Chisq)
Breeding Success (bird ID random)	Infected	4.291	1	**0.038**
Productivity (bird ID random)	Infected	8.252	1	**0.004**

Table 6: Average productivity of Cape Peninsula Black Sparrowhawk individuals listed as infected (n=10), before infection and after infection

	Mean	Standard error
Productivity before infection	1,27	0,09
Productivity after infection	0,45	0,04

Discussion

The incidence of Knemidokoptic mite infections in the Cape Peninsula's population of Black Sparrowhawks potentially constitutes an epizootic event, where a greater number of clinical cases are seen than the usual isolated case appearing at random within a population. More males were infected than expected by chance, but neither dark nor light morphs appeared to be disproportionately infected. This infection also appears to affect mainly adult birds, although monitoring is mainly focused on adults and sub-adults are possibly not as intensively monitored. Sub-clinical levels of infection are low, with most birds examined having no mite presence. This infection has a significant negative effect on productivity and breeding success, although its effect on survival could not be analysed.

Incidence of infection

The reason that I believe the Knemidokoptic mange present in the Cape Peninsula population of Black Sparrowhawks could be considered as an epizootic event is because it is occurring at a far greater frequency in this population than has been recorded anywhere else in Southern Africa. Elsewhere in South Africa there have been only a few single cases reported. The presence of three recent infections in the general Durban area could however indicate the start of an epizootic event in this population of Black Sparrowhawks. One explanation for the higher frequency of infection observed in the Cape Peninsula population could be because of the greater monitoring effort that this population has been subjected to, however, even in other regions with long term monitoring, such as in Kwa-Zulu Natal, or Nysvley, there have only been a few isolated cases reported. Given the diversity of sites around South Africa that have been subjected to scientific study, as well as the lack of response from members of the public who may have seen this infection, I believe that this was a relatively representative survey of the situation of this mite infection within South Africa.

It appears that Knemidokoptic mite infections may be spreading especially quickly in the Cape population. This may be driven by climate directly, or because it may

cause birds in this population have lower immunity to such infections and therefore have difficulty in keeping the infection to a sub-clinical level. The reported number of new infections in 2012 made up 5% of the breeding population, the highest percentage recorded. The number of birds infected and showing clinical symptoms out of the total population (including non-breeding individuals) is likely to be even higher. Knemidokoptic epizootic events from other studies range in prevalence from 4 to 18% prevalence in Red-winged Blackbirds (*Agelaius phoenicus),* Common Grackles (*Quiscalus quiscula),* and Brown-headed Cowbirds (*Molothrus ater)* (Kirmse, 1966)*,* 7 to 25% prevalence in evening grosbeaks (*Cocco*thraustes *vespertinus)* (Carothers, *et al.* 1974), and 60 to 80% in American robins (*Turdus migratorius*) (Pence, *et al*. 1999). Therefore it is not unfounded to believe that 5% prevalence in the Cape Peninsula population of Black Sparrowhawks constitutes an epizootic event.

The mite presence on Black Sparrowhawk carcasses checked for the presence of *Knemidokoptes* spp. indicated that sub-clinical infection is uncommon, contrary to the hypothesis that it would be highly prevalent. This hypothesis stemmed from the idea that only weaker or stressed birds would cross the threshold between sub-clinical and clinical infections, as metabolic stress which causes immunosuppression leads to increased susceptibility to parasitic diseases (Deerenberg, *et al.* 1997; Foldstad & Karter, 1992). The prevalence of subclinical infection of Knemidokoptic mites in both captive and wild birds is undocumented (Pence, et al. 1999). Only one Black Sparrowhawk carcass had evidence of sub-clinical mites, with no serious physical effects. Both birds with very high numbers of mites appear to have died from this infection, with severe physical effects such as baldness and skin lesions present. These would therefore represent clinical cases. The low level of subclinical mite infections may have been due to sampling-although seven slides from each individual was enough to pick up high levels of mite presence, these samples may have missed the infection if present at very low levels. Alternatively the low levels of sub-clinical cases could indicate that most birds in this population are uninfected, with only a small percentage becoming infected, upon which the mite infection becomes clinical. Therefore it appears that once the mite infects the host symptoms become readily apparent, as opposed to

may birds becoming infected and symptoms only appearing when the bird becomes stressed.

Age, sex and morph differences

Knemidokoptic mite infection is more prevalent in male Black Sparrowhawks, and appears to affect mainly adult birds, given that none of the dead juveniles sampled had any mite infection, as well as that no juveniles were among the recorded infected birds. This potentially could indicate greater horizontal than vertical transmission, where unrelated birds such as partners, rather than chicks, become infected. Some mite species are transmitted horizontally when nests are in close proximity, allowing the mites to walk between nests to find new hosts (Clayton & Tompkins, 1994). This is unlikely to be the type of horizontal transmission in Black Sparrowhawks, as their nests are too far apart. Rather the mites may be horizontally transmitted between an infected bird and a bird with which he has physical contact with, such as his breeding partner. The virulence of these horizontal transmissions tends to be greater than vertical transmissions, in terms of reproductive success (Clayton & Tompkins, 1994). The reason for this trend is that vertically transmitted parasites are dependent on the host being reproductively successful (in order to be passed on to a new host), while horizontal parasites are relatively independent of the host's reproduction (Clayton & Tompkins, 1994). I could find no conclusive evidence about in which manner these mites are most likely to be transmitted, and so, although horizontal transmission seems likely, more evidence is needed. It is also possible that chicks and juveniles do become infected from their parents, indicating vertical transmission, but die (or recover) without the infection ever being recorded, or else recognizable symptoms develop too slowly to slowly to be recorded when they are nestlings. Similar to what is observed in Black Sparrowhawks, there is an increased Knemidokoptic mite prevalence in adult Eurasian Tree Swallows (*Passer montanus*) (Mainka, *et al.* 1994), and *Knemidokoptes jamaicensis* infection was only observed on adult Red Crossbills (*Loxia curvirostra*) (Benkman, *et al*. 2005)

The other alternative for the transmission of mites is that each bird gets infected separately from prey items, and not from their breeding partners. The hypothesis that prey may be acting as a vector stems from the fact that Black Sparrowhawks regularly prey on domestic fowl, which are known to be infected by Knemidokoptic mite species (Morishita, 1996). The transmission of Knemidokoptic mites likely requires direct contact, and therefore inter-species transmission is thought to only occur infrequently (Gaudioso, *et al*. 2009). This hypothesis is not based on birds of prey however, which often come into direct contact with other bird species. I was unable to test the prevalence of these mites on prey items, but upon sampling one discarded leg from a domestic chicken killed by a Black Sparrowhawk, Knemidokoptic mites were found. This indicates that prey may be acting as a vector, infecting Black Sparrowhawks with Knemidokoptic mites, although this hypothesis requires further evidence.

In accordance with my findings that more male than female Black Sparrowhawk's were infected, Benkman *et al.* (2005) found that male red crossbills (*Loxia curvirostra*) had a significantly higher incidence of *Knemidokoptes jamaicensis* than females. However, Latta *et al.* (2003) did not find any difference between sexes or age-class in the proportion of Prairie Warblers (*Dendroica discolor)* infected with *Knemidokoptes jamaicensis.* Therefore it appears that any sex-bias in *Knemidokoptes* parasitism is species or population dependent. There are a number of possibilities as to why there may be a sex bias towards male infections. The presence of android hormones such as testosterone can suppress immune function, making males more susceptible to parasitic infection (Foldstad & Karter, 1992). Sexual ornamentation is also thought to reduce immunocompentence (Norris & Evans, 2000), however, as Black Sparrowhawk males are smaller in size, with no obvious sexual ornamentation, this is unlikely to play a role in the sex-biased parasitism found in this species. Behavioral traits specific to males such as territorial disputes or reduced preening during the breeding season may also play a role although evidence for this has not been tested in this population of Black Sparrowhawks. Because Black Sparrowhawk males perform most of the hunting throughout the breeding season and complete the plucking of feathers before feeding the female and juveniles (Brown & Brown, 1979), it is hypothesized that

they are more likely to come into contact with mites that are on prey items. This greater energetic cost at reproduction may additionally put them under more physiological stress than the females, which has been linked to lowered immune function (Deerenberg, *et al.* 1997), making the males more susceptible to infection.

There was no significant difference in the incidence of infection between dark and light morphs. This is despite previous research on this population showing that dark morphs have lower blood parasite (*Haemoproteus nisi*) infection intensity, although no difference in prevalence between morphs was found, indicating equal exposure (Lei, *et al*. 2013). It has been suggested that the ability to resist chronic blood parasite infection may be the reason for the bias towards dark morphs in the Cape Peninsula population (Lei, *et al*. 2013). These results indicate that dark morph Black Sparrowhawks are better able to mount an immune response towards this parasite than light morphs. Similarly, research on feral pigeons indicates that darker morphs are able to control infection by endoparasites better, with greater immune response and lower endoparasitic intensity than light morphs, despite equal exposure to vectors (Jacquin, *et al.* 2011). Therefore, although there is some evidence that parasites can affect one morph more than another, no evidence was found for this in this study, in relation to Knemidokoptic mites.

Breeding success, productivity and survival

Both breeding success and productivity were significantly affected by being infected with Knemidokoptic mites, while survival could not be appropriately analyzed. When comparing some data from infected individuals to the survival probabilities for the whole population it seemed like there may be some negative effect, although not tested statistically. Some studies on bird-parasite interactions have found that survival was not ultimately affected, but breeding parameters were, while others have found significant effects on both. Haematophagous mites (*Dermanyssus gallinae)* had no effect on adult rock dove (*Columba livia)* survival, but negatively affected hatching success, nestling growth rates and post-fledging survival (Clayton & Tompkins, 1995). On the other hand, Latta (2003) found that

there was a significant difference in annual return rate for warblers infected with Knemidokoptic mites, indicating that the infection was likely to negatively affect survival, and Benkman *et al.* (2005) found that survival was depressed with mite infection, especially in male hosts. Therefore although breeding parameters are often suppressed with parasitic infection, survival is not necessarily affected.

The negative effect of mite infection on breeding success and productivity may arise because the adult birds become too agitate to incubate effectively. Physical irritation is a cause of nest failure and desertions in other bird-parasite systems (Duffy, 1983, Clayton & Tompkins, 1995). For example, rock doves infested with *Dermanyssus* mites respond with frequent preening, turning and leg-shaking, and spend less time incubating than uninfected birds (Clayton & Tompkins, 1995). The female Black Sparrowhawks on the Cape Peninsula that have exhibited signs of clinical infection have been reported to be agitated, restless, and nervous of disturbance, often flying off the nest when approached (Koeslag, personal communication, 2013). These behavioral changes will likely disturb incubation, leading to clutch failure. Additionally, if it is the male that is infected, hunting efficiency will be reduced, which in turn will negatively affect breeding performance.

Weather and infections

The average temperature over the winter breeding period (March to October) was most correlated to percentage of the breeding population newly infected each year from 2004 to 2012, although this was not significant. This relationship had a negative trend: when the average temperature for that years winter months was lower, the number of new infections was higher. However, winter rainfall did not appear to be strongly correlated with new infections, nor were either of the summer climate variables. It may be that lower temperatures in winter affect the hunting of prey, which may become more energy intensive. The cold wet winters of the Cape Peninsula may be suboptimal for Black Sparrowhawk hunting, compared to the summer rainfall type climate that predominates in most of the Black sparrowhawk's range. An increase in energy costs due to this suboptimal

winter environment may suppress immune function (Deerenberg, *et al.* 1997) and further cause a low nutritional status and increased physiological stress, which has been linked to increased parasite infection rates (Latta, 2003).

Latta (2003) found that a dry winter desert environment was suboptimal for some species of warblers, with increasing mite infection rates over this period, and that there was a negative association between rates of infestation of Knemidokoptic mites and rainfall. The mites of this system seemed to favour dry, winter conditions (Latta, 2003). Benkman *et al.* (2005) found that the largest decrease in Knemidokoptic mite prevalence occured during the warmest and driest year. Therefore it is not known whether dry conditions or cold conditions are more optimal for Knemidokoptic mites, but it may be that the winter period is key to increasing infections. It seems unlikely that the spread of the Black Sparrowhawk range to a completely new winter climate regime and this epizootic event are unrelated, given the low infection rates found elsewhere in South Africa. Additionally, when a correlation analysis was run between the number of infected 'pair years' from around South Africa and climate variables for each of these locations, the correlation between winter rainfall and number of pairs was strongest, although not significant. This could potentially indicate that this variable may also play a role in the transmission of Knemidokoptic mites at locations around the country.

Limitations and future research

Although in this study I have attempted to review and summarise infection incidences of this mite in South Africa, the occurrence of it outside of South Africa is still unknown. It may be possible that there are infection events elsewhere in the Black Sparrowhawk's wider African range. A survey of wider scope may be useful as this species covers a wide range of habitat, climate and urbanization gradients and any patterns in infection can be used to find possible causal factors. Although infection incidences occurred in the Durban area, and singly elsewhere, it was only assumed that these were also caused by Knemidokoptic mites- no samples were obtained to check whether this was definitely the case. The great similarity in

symptoms makes it very likely that *Knemidokoptes spp.* were responsible however. Efforts to identify the mites to species level are ongoing, with Dr. Helene Steenkamp of the National Zoological Gardens of Pretoria.

It must be recognized that the role weather could play in infections was not adequately addressed in this study. The nature of the data was collected in the past was the main reason for this. The data was collected by recording new infection each year, but it would have been better if the month or even season that the bird became infected was recorded. From this it would then be possible to find what season, or months lead to most new infections, if any. It would then be feasible to discover if seasonal effects are causing infections, perhaps due to the range expansion to the different climate regime of the Cape Peninsula. In future, all data recorded should note the month the infection was first seen. Another climate variable that would be of interest for further study is humidity. Low humidity has been found to reduce the number of ectopasitic lice on birds, causing substantial variation in parasite pressure in different host populations (Moyer, *et al*. 2002). Humidity is higher along the coastal regions of South Africa (Intellicast, 2013), and especially in the Kwa-Zula natal region. As all infection incidences occurred in coastal regions, the effect of humidity on Knemidokoptic lice warrants further investigation.

Although it was not possible to find a breeding pair of infected birds in order to do a behavioral analysis, this is recommended for further research. Two photographs were taken of two different infected females visiting a nest built by another uninfected pair. Both of these birds were heavily infected, and it may be that these two birds were looking to take over an uninhabited nest because they were unable to build their own due to their infection. This kind of behavior (visiting other nests already in use) is not often observed and warrants further investigation. Further, alterations in the breeding behavior, such as interrupted incubation or reduced copulation attempts are important to quantify, as this interrupted behavior is hypothesized to be responsible for the negative effect of infection on breeding success and productivity. Additionally, the post-mortem Black Sparrowhawk was found to have no fat reserves and severe pectoral muscle atrophy, indicating that

this bird may not have been hunting efficiently. Similarly American robins (*Turdus migratorius*) with Knemidokoptic mite infections were observed to be lethargic, and did not attempt to feed (Pence, *et al.* 1999), and Latta (2003) found that mite parasitized Warblers had reduced muscle mass scores. This indicates that mite infestation potentially could affect the feeding of hosts. Therefore it would be of interest to see if clinically infected Black Sparrowhawks alter their feeding behavior. The proposed hypothesis that this infection mainly affects adult birds is based on the absence of any reports of juveniles or chicks displaying symptoms. As most chicks are ringed when they are still in the nest it seems unlikely that this infection would not have been picked up, if it were present. This is however dependent on the length of time it takes before symptoms develop. However, it would be of interest to study the chicks of pairs with an infected bird, to see if this infection is readily passed on to the chicks.

Conclusion

This is the first study of Knemidokoptic mite infection in the Cape Peninsula population of Black Sparrowhawks, and the first note of the potential of these mites to cause an epizootic event within one wild population of birds of prey. All other cases of infection by these mites occurred on lone, usually captive, birds of prey. The prevalence of this infection in the Cape Peninsula population seems unusually high, with 5% of the breeding population infected in 2012. This infection has a significant negative effect on breeding success and productivity, which has the potential to affect the stability of this population over time. If more and more birds become infected it is likely that this population will start decreasing in numbers. Male birds are especially affected by this infection, most likely because of the greater energetic costs they bear at breeding. This may weaken their immune systems, or expose them to more vectors than females or juveniles. This infection appears to be horizontally transmitted, that is, from partner to partner, as no chicks or juveniles have ever been reported as showing signs of infection. However it may be likely that birds become infected individually from another source, such as prey, and not through contact with birds of their own species. More research needs to be conducted to ascertain whether these birds of

prey are becoming infected through their prey items, or through some other means.

Although rainfall level does not seem closely related to infection level, cold weather potentially could be an important factor, where hunting becomes more energy intensive leading to lowered immune function, allowing sub-clinical infections to become clinical. Other studies have generally found that Knemidokoptic infections increase in winter months. More research needs to be conducted in order to find whether the Cape Peninsula's winter climatic regime is causing this epizootic event. The occurrence of 3 recent infections in the Durban area may be the start of another epizootic event, which would discount the hypothesis that the Cape Peninsula's weather is a driving factor of infection, or indicate a coastal climate factor as causal.

Although the population of Black Sparrowhawks has been steadily increasing since their colonization of the Cape Peninsula, Knemidokoptic mite infections may now threaten this growth. The potential of this infection to affect this population stems mainly from its negative effect on breeding success and productivity. This negative effect is in line with the original hypothesis that this infection negatively affects fitness. Although this species is not listed as threatened, due mainly to its wide range and ability to succeed in an urban environment, this case study is interesting in terms of parasite-host dynamics potentially being very dependant on the host's environment. Also, this first report of significant numbers of clinical Knemidokoptic mite infections in a wild bird of prey population is significant for the field of bird-parasite interactions. This epizootic event may also be the first indication of a negative consequence to the expansion of the Black Sparrowhawk's range to a different climatic zone, or to its success in an urban environment.

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Appendix

Ring numbers could be identified for 5 of the 11 infected breeding individuals for their survival record, and the breeding record could be found for 10 of the 11 breeding infected individuals, due to the ringing of its known partner/s. Nine other birds were identified to be infected, but were not part of a breeding pair, and therefore no breeding or survival data could be found (see Table 2). No record can be kept for elusive single birds, and as these instances were recorded opportunistically when a bird was sighted, these instances of infection were excluded from statistical analysis.

Table 1: Characteristics of Infected Black Sparrowhawks of the Cape Peninsula study individuals (breeding only)

Territory	Year	Sex (M=male F=female U=unknown)	Morph (L=light D=dark	Featherloss on head (1=present, 0=absent)	Leg lesions (1=present, 0=absent)	Ring Number	Date Ringed	Unringed/Other	Current fate
Newlands 2	2007	M	L	1	0	-	-	unringed	Suspected dead 2007
Lower Tokai Forest	2007	F	D	1	0	-	-	LTF1F1	Suspected dead 2010
Pagasvlei	2007	M	D	0	1	687858	12.09.2007	-	Suspected dead 2011
Northern Border	2008	M	L	1	0	-	-	unringed	Suspected dead 2008
Ottery	2011	M	D	1	0	-	-	unringed	Alive 2012
Dassenberg	2011	F	D	1	0	-	-	unringed	Alive 2012
Klein Leeukoppie	2012	M	D	1	0	6HO3248	13.9.2010	-	Alive 2012
Westlake	2012	M	L	1	0	687869	08.11.2006	-	Alive 2012
Ruyteplaatz	2012	M	D	1	1	687876	27.07.2008	-	Confirmed Dead (07 2012)
Rifle Range	2012	F	D	1	0	784931	Unknown	-	Alive 2012
Imhoff 1	2012	U	L	1	0	-	-	unknown	Alive 2012

Table 2: Characteristics of infected Black Sparrowhawk study individuals, which are not part of breeding pair

Territory	Other area	Year	Sex (Male=M female=F unknown=U)	Morph (L=light D=dark)	Featherloss on head (1=present, 0=absent)	Leg lesions (1=present, 0=absent)
Klein Leeukoppie		2005	M	D	1	0
	Marina da Gama	2007	U	D	1	0
	Marina da Gama	2007	U	L	1	0
Rondevlei		2007	M	D	0	1
Lower Tokai Forest		2008	M	L	1	0
	Marina da Gama	2010	U	D	1	0
Tokai Picnic		2011	M	D	1	0
	Plumstead	2012	U	D	1	0
	Noordhoek, Emerald Way	2013	U	L	1	0

Table 3: Observed and expected numbers of infection for dark and light Black Sparrowhawk morphs, where 76% of Cape Peninsula population is dark (n=20)

Morph	Observed number of infections	Expected number of infections (n*proportion of pop. of that morph, where dark=0.76, light=0.24)
Dark	13	15,2
Light	7	4,8

Table 4: Observed and expected numbers of infection of male and female Black Sparrowhawks, where the sex ratio is 1:1 (n=14)

Sex	Observed number of infections	Expected number of infections (n* proportion of pop. of that sex, where male=0.5, female=0.5)
Male	11	7
Female	3	7

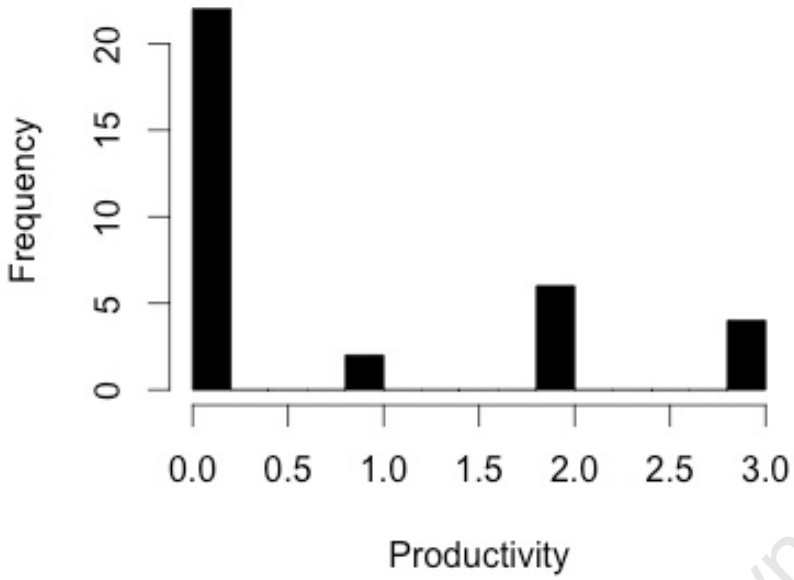

Figure 1: Frequency histogram of Black Sparrowhawk productivity, showing an approximate Poisson distribution (zero inflated)

ANN KOESLAG

Scaly-face mite infections in BLACK SPARROWHAWKS

Researchers monitoring the population of Black Sparrowhawks *Accipiter melanoleucus* on the Cape Peninsula in the Western Cape have discovered an unusual parasitic infection that appears to be occurring at increasing levels. The scientists are now asking the public to report sightings of affected birds.

Microscopic *Knemidocoptes mutans* mites are parasites that burrow under the skin on the legs or crown of birds and cause a type of avian mange. More commonly known as scaly-leg or scaly-face mite, it results in feather loss on the crown and encrustations or lesions on the legs of the bird. In extreme cases the mite infection results in missing digits, and a completely bald bird. The condition is thought to have a negative effect on the bird's breeding success and survival.

Infection is common in caged birds, but there have been increasing reports of it occurring in wild bird species. Wild hosts are often migratory passeriform birds such as warblers, but are almost never birds of prey. In South Africa, two species are known to be badly affected: the Cape Wagtail *Motacilla capensis* and, surprisingly, the Black Sparrowhawk. Within the Cape Peninsula, 20 Black Sparrowhawks have been recorded with this condition in the past six years.

above *A Black Sparrowhawk badly affected by scaly-face mites, as shown by considerable feather loss around its head.*

Very little is known about the parasite and its effects, and until now there have been just six scientific papers published on this infection in wild birds anywhere in the world. Only one of these studies is occurring in Africa.

Research is currently under way to investigate the manifestation of this mite in Black Sparrowhawks and its effect on individual birds. The research will mostly focus on the sparrowhawks that breed in and around the Cape Peninsula, which have been the core of a long-term monitoring programme by Ann Koeslag and her team (*http://blackspar1.wordpress.com/*).

However, the researchers are also interested in the prevalence of this condition beyond the Cape Peninsula population. Therefore, if you have any sightings of balding Black Sparrowhawks, such as the bird in this photograph, from elsewhere in Africa, you are requested to report them to Dr Arjun Amar (e-mail *arjun.amar@uct.ac.za* or tel. +27 (0)21 650 3304) or Julia van Velden (e-mail *juliavanvel@yahoo.com*).

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Figure 2: African Birdlife article, calling for sightings of Black Sparrowhawks with symptoms of mite infections around Africa